Therapeutic Agents

The present invention relates to agents which are useful in the diagnosis and treatment of malignancies such as cancer therapy, to processes for their production and to pharmaceutical compositions containing them.

Apoptotic cell death is characterised by loss of cytoplasmic material, nuclear changes with marginalisation of chromatin and by the formation of apoptotic bodies (L.M. Schwartz et al., Immunol. Today 1993, 14:582-590, D.J. McConkey et al. Mol. Aspects Med. (1996) 17:1-115, J.F.Kerr et al., Cancer (1994) 73:2013-26). The reduction in cell viability is accompanied by DNA fragmentation that proceeds in steps with initial formation of high molecular weight (HMW) DNA fragments (50-300kbp) and the subsequent appearance of oligonucleosome length DNA fragments consisting of oligomers of approximately 200bp. (M.J. Arends et al., Am. J. Pathol. (1990) 136: 593-608, B. Zhivotovosky et al., FEBS Lett. (1994) 352;150-4). Cytoplasmic proteases and Ca^{2+}-dependant signaling pathways are activated prior to DNA fragmentation, and are regarded as a prerequisite for the nuclear changes (B. Zhivotovsky et al. Exp. Cell Res. (1995) 221:404-412m S.Kumar et al., TIBS, (1995) 20:198-202). Agonists like Fas-ligand and TNF first bind to cell surface receptors and then activate transmembrane signaling events that cause cytoplasmic and nuclear changes (L.G. Zheng et al., Nature (1995) 377: 348-351, W.P. Declercq et al, Cytokine (1995, 7:701-9, T.S. Griffith, Science, (1995) 270:1189-1192). Endonuclease activation and DNA fragmentation require that signals from the cytoplasm reach the nucleus. The mechanisms of nuclear uptake and signaling across the nuclear membrane in apoptotic cells remain poorly understood.

The transport of macro-molecules from the cytoplasm into the nucleus is highly regulated. Nuclear pore complexes (NPCs) are the sites of exchange of macromolecules between cytoplasm and nucleoplasm (D.A. Jans et al., Physiol. Rev (1996) 76: 651-

5   685, D. Gorlich et al., Science (1996) 271:1513-1518, and Y. Yoneda, J. Biochem. (1997) 121:811-817). The NPCs allow passive diffusion of molecules smaller than 30 kDa but larger proteins like ovalbumin are delayed and bovine serum albumin (66kDa) does not enter the nucleoplasm. Entry of large

10   molecules or complexes into the nucleus requires active transport and is commonly carrier mediated. The specificity for the carrier may be determined by the so called nuclear targetting or nuclear localization sequences (NLS) that characterize proteins with the ability to enter the nucleus.

15   For example, binding of glucocorticoids to their receptor releases HSP 90 that binds to unoccupied receptors and reveals a NLS in the glucocorticoid receptor sequence that leads to the transport of the glucocorticoid ligand-receptor complex into the nucleus (J. Yang et al., Mol. Cell. Biol. (1994) 14:

20   5088-98 issn 0270-7306).

A protein complex obtainable from milk that induces apoptosis in tumour cells and immature cells but spares other cells has been described previously (Proc. Natl. Acad. Sci, USA, 92,

25   p8064-8068). The active fraction was initially isolated from human casein by ion-exchange chromatography and was shown by N-terminal amino acid sequencing and mass spectrometry to contain an oligomeric form of α-lactalbumin (described as a multimeric form or "MAL"). Monomeric α-lactalbumin is the

30   major protein component in human milk whey, where it occurs at concentrations around 2mg/ml (W.E. Heine et al., J. Nutr. (1991) 121: 277-83), but monomeric α-lactalbumin isolated from human whey did not induce apoptosis. Further analysis has provided evidence that the apoptosis-inducing fractions

35   contains oligomeric forms of α-lactalbumin with structural properties distinct from monomeric α-lactalbumin as it occurs

in whey. The apoptosis inducing fraction is referred to
hereinafter as MAL.   It is possible that the mechanism by
which the oligomer induces apopotosis may relate to the Ca^{2+}
binding properties of MAL since apoptosis required

5   extracellular calcium.

MAL may be derived from other sources of α-lactalbumin such as
bovine, sheep or goats milk or human whey.

10   It has now been found that MAL is taken up by susceptable
cells (i.e. tumour cells) and accumulated in cell nuclei.
This high uptake by the nucleus, combined with its oligomeric
protein structure, means that MAL would provide a useful
carrier for other moieties for example, cytotoxins or

15   chemotherapeutic agents whose effect would supplement the
effect of MAL in killing tumour cells, or diagnostic reagents
such as dyes or radio- or other labels which would allow
identification of tumour cells, whilst at the same time,
allowing MAL to exert a killing effect on those cells.

20
INS B4)
The present invention provides an agent comprising a protein
complex comprising an oligomeric form of α-lactalbumin (MAL)
and a further reagent which is combined with MAL such that it
is carried into the nucleoplasm of cells which are susceptible
25   to MAL.

The said further reagent may be coupled by conjugation or by
covalent bonding for example by way of a linking or spacer
group as would be understood in the art. Enzymatic reactions
30   can mediate or facilitate the coupling.

Recombinant production techniques allows also the possiblity
that MAL could be produced in the form of a fusion protein
with the said further reagent.

35

Examples of said further reagents include cytoxins such as
known chemotherapeutic reagents used for the treatment of

cancer, microbial toxins such as diptheria toxin and monoclonal antibodies.   Alternatively, the said further reagent comprises a labelling agent such as biotin or radioactive labels such as ^{125}I. For example, a labelling group

5   can be introduced into a protein using an enzymatic reaction or by having a labelled building stone (such as radioactive isotopes e.g. ^{14}C, ^{35}S,) within the protein. ^{125}I-labelling can be performed enzymatically by coupling ^{125}I to the protein with the help of lactoperoxidase.   Biotinylation of the protein is

10 performed by letteing D-biotinoyl-ε-aminocaproic acid-N-hydroxysuccinimide ester react with the protein by forming a stable amide bond to free amino groups in the protein.

    Protein may also be labelled by adding radioactive amino acid

15 during the production of a recombinantly produced protein.

    Depending upon the nature of the said further reagent, the complex of the invention can be used in the diagnosis and/or treatment of cancer. For this purpose, the complex is

20 suitably formulated as a pharmaceutical composition and these form a further aspect of the invention.

    The complex can be administered in the form of an oral mucosal dosage unit, an injectable composition, or a topical

25 composition. In any case the protein is normally administered together with the commonly known carriers, fillers and/or expedients, which are pharmaceutically acceptable.

    In case the protein is administered in the form of a solution

30 or cream for topical use the solution contains an emulsifying agent for the protein complex together with a diluent or cream base. Such formulations can be applied directly to the tumour, or can be inhaled in the form of a mist into the upper respiratory airways.

35

    In oral use the protein is normally administered together with a carrier, which may be a solid, semi-solid or liquid diluent

or a capsule. Usually the amount of active compound is between 0.1 to 99% by weight of the preparation, preferably between 0.5 to 20% by weight in preparations for injection and between 2 and 50% by weight in preparations for oral administration.

5

In pharmaceutical preparations containing complex in the form of dosage units for oral administration the compound may be mixed with a solid, pulverulent carrier, as e.g. with lactose, saccharose, sorbitol, mannitol, starch, such as potato starch,

10 corn starch, amylopectin, cellulose derivatives or gelatine, as well as with an antifriction agent, such as magnesium stearate, calcium stearate, polyethylene glycol waxes or the like, and be pressed into tablets. Multiple-unit-dosage granules can be prepared as well. Tablets and granules of the

15 above cores can be coated with concentrated solutions of sugar, etc. The cores can also be coated with polymers which change the dissolution rate in the gastrointestinal tract, such as anionic polymers having a pk_a of above 5.5. Such polymers are hydroxypropylmethyl cellulose phthalate,

20 cellulose acetate phthalate, and polymers sold under the trade mark Eudragit S100 and L100.

In preparation of gelatine capsules these can be soft or hard. In the former case the active compound is mixed with oil, and

25 the latter case the multiple-unit-dosage granules are filled therein.

Liquid preparations for oral administration can be present in the form of syrups or suspensions, e.g., solutions containing

30 from about 0.2% by weight to about 20% by weight of the active compound disclosed, and glycerol and propylene glycol. If desired, such preparations can contain colouring agents, flavouring agents, saccharine, and carboxymethyl cellulose as a thickening agent.

35

The daily dose of the active compound varies and is dependant on the type of administrative route, but as a general rule it

is 1 to 100 mg/dose of active compound at personal
administration, and 2 to 200 mg/dose in topical
administration. The number of applications per 24 hours depend
of the administration route, but may vary, e.g. in the case of
5   a topical application in the nose from 3 to 8 times per 24
hours, i.e., depending on the flow of phlegm produced by the
body treated in therapeutic use.

The invention further provides a method for treating cancer
10   which comprises administering to cancer cells a complex or a
composition as described above.

Diagnostic applications of the complex of the invention may be
carried out *in vivo* or *in vitro* for example on biopsy samples.
15   For this purpose, a complex comprising a label may be applied
to the suspect tumour in the form of a pharmaceutical
composition when used *in vivo* or any formulation when used *in
vitro*.   The tumour can then be observed in order to determine
whether the complex penetrates into the nucleus or not.
20   Visibility of the nucleus would be indicative that the complex
has been absorbed into the nucleus and is a MAL susceptible
tumour.   Although the degree of uptake of MAL is variable, it
is taken up by cancer cells generally and therefore may be
used in killing those cells, particularly when combined with
25   another cellular toxin in a complex of the invention.   Uptake
of MAL is particularly high in lymphoid tumour cells such as
leukaemia cells.   Even in carcinoma cells such as lung cancer
cells, there is sufficient uptake to result in cell death as
will be illustrated hereinafter. The information obtained
30   using diagnostic methods of the invention may assist in
determining a future treatment regime.

The interaction of MAL with different cellular components was
studied by confocal microscopy, using biotinylated MAL, and by
35   subcellular factionation using ^{125}I-labelled MAL. Monomeric α-
lactalbumin and human IgG were used as controls.

MAL was found to accumulate in cell nuclei rather than the cytosol, the vesicular fraction or the ER-Golgi complex. The nuclear accumulation of MAL occurred rapidly in cells that were susceptible to its apoptosis-inducing effects, but not in

5 resistant cells. Nuclear uptake was through the nuclear pore complex and was critical for the induction of apoptosis, since inhibition of nuclear uptake with WGA rescued digitonin-permeabilized cells from apoptosis. Ca^{2+} was required for MAL induced DNA fragmentation but nuclear uptake of MAL was

10 independent of Ca^{2+}.

The results demonstrated that MAL can target cell nuclei and that nuclear targeting mechanisms are more readily available in cells that are sensitive to MAL-induced apoptosis than in resistant cells. It appears that apoptosis induction occurs

15 at least in part through a direct effect of MAL at the nuclear level.

Cell surface binding of MAL as a possible decisive step in apoptosis induction was investigated first. Exogenous apoptosis-inducing molecules like Fas-ligand or TNF bind to

20 their respective cell surface receptors and trigger transmembrane signalling event and intracellular pathways leading to apoptosis. MAL bound quickly to cell surfaces, was saturate at high MAL concentrations and was specific as defined by competition experiments where labelled MAL was

25 competed out by unlabeled MAL. By confocal microscopy MAL was shown to bind in patches, suggested that either MAL bound as preformed aggregates, or that the bound MAL accumulated in certain areas of the membrane through capping or other mechanisms influencing receptor distribution. There was

30 little quantitative difference in cell surface binding of monomeric, inactive and oligomeric, active forms of the protein. Furthermore, there was no difference in cell surface binding to sensitive and resistant cells. The results suggested that MAL differs from agonists like TNF and Fas-

35 ligand in that cell surface binding does not itself trigger apoptosis. Recently Sheridan et al.(Science, (1997) 277:818-

821 and Pan et al. (Science (19970 277:815-818) described a
decoy receptor lacking the signalling domain of the native
receptor, in the membrane of healthy cells [Pan, 1997 #640, ;
Sheridan, 1997 #639]. The TRAIL protein binds cell surface
5 receptors with similar affinity, but will not be able to
induce an apoptosis-signal in healthy cells.

MAL was rapidly taken into the nuclei of cells that were
sensitive to its apoptosis inducing effect, suggesting that it
was capable of nuclear targeting. This term is used herein
10 to describe preferential localisation of certain molecules to
the nuclear compartment. Molecules of diverse origin,
structure and function share the ability to reach cell nuclei,
and may exert their main functions there as opposed to the
cytoplasmic compartment. The uptake of MAL into the nucleus
15 was via the nuclear pore complex as shown by inhibition
studies using WGA, a lectin that binds to glycosylated regions
of the nucleoporins and sterically hinders transport of the
importin-protein complex through the nuclear pore (S.A. Adam
et al., (1990) J. Cell Biol. 111:807-816). WGA treatment
20 blocked MAL uptake into the nuclei of digitonin-treated cells
and inhibited the MAL-induced DNA fragmentation. The
structural basis for and mechanism of nuclear uptake of MAL
need to be identified. Classical nuclear targeting sequences
often include clusters of basic amino acids, that share little
25 or no sequence homology (Jans et al. (1996) supra., J. Garcia-
Bustos et al., Biochim Biophys. Acta. (1991) 1071: 83-101).
Sequence analysis of the monomeric form of α-lactalbumin did
not show the presence of known nuclear targeting motifs and
the monomer did not target cell nuclei. It is likely,
30 therefore that MAL carried structural modifications that
confer affinity for the nuclear compartment, the nuclear
membrane and/or the nuclear pore.

The susceptibility to MAL-induced apoptosis in difference
cells was proportional to the nuclear accumulation of MAL.
35 MAL rapidly entered the nuclei of the sensitive L1210 cells.

At a concentration of 0.3mg/ml nuclear staining was observed
after 1 hour in 10% of cells and increased to 75% after 6
hours. DNA fragmentation was first seen after 6 hours
incubation .   Nuclear uptake occurred more slowly in the
5   intermediary sensitive A549 cell line and was low or absent in
human kidney cells.

The difference was not observed when the total, cell-
associated MAL or cytoplasmic uptake of MAL was compared
between the cells. Uptake into the cytoplasm occurred with
10 similar kinetics in the L1210, A549 and HRTEC cells. The
total amount of intracellular MAL was highest in the L1210
cells but most of this was in the nuclei and not in the
cytoplasm.   This suggested that the nuclear uptake was the
decisive step. Further evidence for a direct effect of MAL at
15 the nuclear level was obtained using isolated nuclei. MAL
induced DNA fragmentation in isolated nuclei at concentrations
lower than those required for whole cells.   It should be
noted that isolated nuclei from the three cell types were all
susceptible to the effects of MAL and showed similar kinetics
20 of DNA fragmentation. (HMW-oligonucleosome length fragments.
Differences between intact nuclei and isolated nuclei).
These results suggested that the decisive event separating
sensitive from resistant cells was the actual transport of MAL
from the cytoplasm into the nuclei, rather than the effect of
25 MAL once in the nuclear compartment.

Lactalbumins are Ca^{2+} binding proteins with one high affinity
and one low affinity Ca^{2+} binding site (J. Ren et al., J. Biol.
Chem. (1992) 268:19292-8).   MAL induced apoptosis was
previously shown to require extracellular Ca^{2+} (A. Håkansson et
30 al., (1995) supra.). In this study, the applicants examined
the effect on nuclear targeting and on DNA fragmentation of
various agents that alter extra- or intracellular Ca^{2+} levels.
Pre-treatment of sensitive cells with Ca^{2+}-chelators was found
to inhibit MAL-induced DNA fragmentation in isolated nuclei.
35 There was however no effect on the nuclear targetting process.
These observations suggested that apoptosis occurs as a result

of two converging mechanisms; the transport of MAL to the nucleus and changes in the available Ca^{2+} concentration.

Therefore, when applying the treatment of the invention for example by using a pharmaceutical composition, care should be taken that the calcium levels are sufficient to ensure that cells can be killed. However high calcium levels can lead to inactivation of MAL. Therefore, the inclusion of calcium agents in the formulation should be avoided.

MAL contains as its major constituent oligomers of α-lactalbumin. The α-lactalbumin protein family has been extensively studied and characterised at the molecular level. Lactalbumins from different species show little structural variation, but the amounts are higher in e.g. human compared with bovine milk. The monomeric form of α-lactalbumin has a molecular mass of 14kDa and is the quantitatively dominating whey protein in human milk (W.E. Heine et al., (1991)supra.). MAL, on the other hand, was not derived from whey but from casein fraction of human milk after precipitation at low pH. The active fraction bound with high affinity to an ion-exchange matrix, eluted with high salt and was found to contain several oligomeric forms of α-lactalbumin. Low pH and variable anionic conditions have previously been shown to alter the molecular structure of monomeric α-lactalbumin to the so-called molten globule state, Molten globules are partially unfolded intermediates between the native and fully denatured forms of α-lactalbumin (K. Kuwajima., Faseb J. (1996) 10:102-109, A. Alexandrescu et al., Biochemistry (1993) 32: 1707-1718). Preliminary results from structural studies suggest that MAL contains partly refolded oligomers with structural features distinct from the monomeric α-lactalbumin as it occurs in human whey.

Additionally MAL often contains lipids and in particular MAL derived from human milk contains phospholipids, monoglycerides, diglycerides, cholesterol, triglycerides and

free fatty acids. Specifically the free fatty acid content of MAL appears to be higher than that found in fresh milk. The role of these lipids in apoptosis or in the stabilisation of the MAL structure is not fully clear. However, the presence of these components in MAL is preferred for its therapeutic effect.

This study confirmed the difference in apoptosis inducing activity between MAL and monomeric α-lactalbumin, and showed distinct difference in their cellular interactions. Monomeric α-lactalbumin bound to cell surfaces and entered the cytoplasm, but did not accumulate in cell nuclei. There was no effect of α-lactalbumin at the nuclear level even in digitonin-permeabilized cells, when the protein was allowed to diffuse freely into the nuclei. Furthermore, these was no difference in subcellular distribution of the monomer between apoptosis sensitive and resistant cells. The results demonstrate that structural modifications or additional milk constituents present in MAL are required for nuclear targeting and induction of apoptosis.

Human milk provides the breast-fed infant with a mucosal immune system. Molecules in milk prevent microbial attachment to mucosal tissues, lyse viral particles, disrupt bacterial cell walls and prevent microbial growth (H. McKenzie et al., Adv. Protein Chem., (1994) 44: 173-313, J.J Kabara et al., Antimicrob. Agents Chemother (1972) 2:23-28, F.D. Gillin et al., Science (1983) 221: 1290-1292). Epidemiological studies consistently find lower frequencies of viral and bacterial infections in breast-fed infants. Epidemiological studies have also provided compelling evidence that breast-feeding may protect against cancer. Breast-fed individuals have a lower incidence of lymphomas and other malignancies, and the frequency decreases with the length of breast-feeding (M.K. Davis et al., Lancet (1988) ii: 365-368). There are other reports to suggest that the breast cancer incidence is reduced in women who breast-feed their children (V. Siskind et

al., Am. J. Epidemiol. (1989) 130: 229-236, P.A. Newcomb et
al., N. Engl. J. Med. (1994) 330: 81-87) Our studies provide
a potential mechanism for the reduced disease frequencies.
MAL may reach the rapidly proliferating cells in the gut of

5   the breast-fed infant and drive selection through maturity and
away from the neoplasia or reach the mucosa-associated
lymphoid tissue and influence the function of local lymphocyte
populations.

10   The invention will now be particularly described by way of
example with reference to the accompanying diagrammatic
drawings in which:

|NS B5)

     Figure 1A shows the results of viability studies on the
15   incubation of three cell types with different concentrations
of MAL incubated for different lengths of time. The viability
was determined by trypan blue exclusion as % of cells exposed
to medium alone;

20   Figure 1B shows the chromatin cleavage induced by MAL in these
cells at various time points as measured by field inverse gel
electrophoresis (panel I) and the oligonucleosome-length DNA
fragmentation as analysed by conventional gel electrophoresis
(panel II).

25
     The cells were incubated with the concentration of MAL killing
50% of the cells (LD_{50} concentration)after 6h (L1210) or 24h
(A549 and HRTEC cells). The LD_{50} concentration for the
different cells was 0.5 mg/ml for L1210 cells, 1.25 mg/ml for
30   A549 cells and 4.5 mg/ml for HRTEC cells;

     Figure 2A shows the cell surface binding of biotinylated MAL
(d) and α-lactalbumin (c) with streptavidin (a) and Ig G (b)
as controls as visualised by confocal microscopy;

35
     Figure 2B shows the cell associated radioactivity in L1210,
A549 and HRTEC cells after 30 min exposure to increasing

concentrations of radiolabeled MAL (—▢—), ALA (—▢—) or IgG (—O—).

Figure 3 shows interaction of MAL with different cellular
5 compartments in A549 cells. (a) Streptavidin control. (b) Cell
surface binding detected after 30 min incubation. The
morphology and intensity of MAL cell surface binding was
similar for the three cell types, and for ALA. (c)
Cytoplasmic, granular fluorescence was detected after 3 h
10 incubation with MAL. (d) Nuclear accumulation was maximal
after 24 h incubation. The nuclear accumulation was more rapid
in the L1210 cells. Nuclear accumulation of MAL was not
observed in the HRTEC cells. The scale bar units are in µm;

15 Figure 4 shows localization of ^{125}I-labeled MAL to different
subcellular compartments in L1210, A549 and HRTEC cells. Cells
were exposed to 10^6 cpm of radiolabeled MAL, homogenized, and
radioactivity associated with each subcellular fraction was
quantitated in a γ-counter. The nuclear fraction contained
20 mostly nuclei, pellet 2 contained plasma-, Golgi-, ER-
membranes and mitochondria, pellet 3 contained small vesicles
and the supernatant contained the cytosol;

Figure 5 illustrates difference in subcellular distribution
25 between MAL and ALA. L1210, A549 and HRTEC cells were exposed
to 10^6 cpm of radiolabeled proteins for 6 h, 24 h and 24 h,
respectively. The cells were homogenized, subjected to
differential centrifugation and the radioactivity of each
subcellular fraction was determined
30
Figure 6 illustrates the chromatin cleavage induced by MAL in
L1210, A549 and HRTEC nuclei after 2 hours incubation with
0.4mg/ml of MAL. For inhibition experiments, the isolated
nuclei were preincubated with 50µg/ml of WGA before the
35 addition of protein. Chromatin cleavage was analysed by
field-inverse gel electrophoresis (top) and oligonucleosomal

14

fragmentation was detected by conventional gel electrophoresis (bottom);

Figure 7 shows nuclear uptake of MAL, ALA and IgG into the
5   nuclei of digitonin-permeabilized A549 cells. Digitonin –
permeablized cells were incubated with biotinylated protein
for 20 minutes, washed, counterstained with FITC-conjugated
strepavidin (green colour) and visualised by confocal
microscopy. Nuclear DNA was counterstained with 25µg/ml of
10   propidium iodide (red colour). Nuclear staining is shown for
cells exposed to streptavidin alone (a) IgG (b) ALA (c and d)
and MAL (e and f). For inhibition experiments the digitonin-
permeabilized cells were preincubated with 50µg/ml of WGA
before the addition of biotinylated protein. Nuclear uptake
15   of MAL was inhibited with WGA (f), but ALA was still taken up
(d); and

Figure 8 shows the effect of subcellular distribution of MAL
after treatment with Ca^{2+} inhibitors. L1210 and A549 cells
20   were pretreated with 0.5mM BAPTA/AM, 10µM verapimil or 5µM
nefidipine before exposure to 10^6cpm of radiolabelled proteins
for 6 hours and 24 hours respectively. The cells were
homogenized, subjected to differential centrifugation and the
radioactivity of each subcellular fraction was determined.

25   INS
     In the examples, the following reagents were used:

     INS B6)
        FITC conjugated swine anti-rabbit antibodies, and FITC
     conjugated streptavidin were from Dakopatts a /s (Glostrup,
30   Denmark). DEAE-Trisacryl M was from BioSepra (Villeneuve la
     Garenne, France). The Biotin Labelling kit was from Boeringer
     Manheimer GmbH (Germany) and ^{125}I was from Amersham (UK).
     Flowcheck™ and Flowser™ fluorospheres were from Coulter Inc.
     (Hialeah, FL, USA). Seaplaque GTG Low melting temperature
35   agarose gel and SeaKem GTG agarose were from SeaKem, FMK
     Bioproducts (Rockdale, USA). Dulbecco's modified Eagle's

medium, Hank's balanced salt solution (HBSS), RPMI 1640, fetal calf serum (FCS), L-glutamine, 2-mercaptoethanol, penicillin, streptomycin, gentamicin and 1 kD DNA ladder was from Gibco/BRL, Life Technology Ltd (Paisley Scotland, UK). Boric
5   acid, dimethylsulfoxide, Na_2HPO_4, NaCl, KH_2PO_4, $MgCl_2$, NaAzid, Tween-20 and tris(hydroxymethyl) aminomethane was from Kebo Lab (Stockholm, Sweden). The PD-10 column, heparin and percoll solutions were from Pharmacia Biotech (Stockholm, Sweden), α-lactalbumin, leupeptin, antipain, PMSF, Triton X-100, NP-40,
10   CHAPS, trypsin, butyrate, N-lauroylsarcosine, sodium periodate, proteinase K, tunicamycin, lactoperoxidase, EDTA, EGTA, collagenase type I, DNAse type IV and two sets of pulse markers: chromosomes from *Saccharomyces cerevisiae* (225-2200 kbp) and a mixture of λDNA Hind III fragments, λDNA and λDNA
15   concatemers (0.1-200kbp) were from Sigma Chemicals Inc (St Louis, USA).

The murine lymphoblastoid leukemia cell line L1210 (ATCC CLL 219) was cultured in in RPMI 1640 supplemented with 10% FCS, 2
20   mM glutamine and 50µg of gentamicin per ml with the addition of 50 µM 2-mercaptoethanol. Cells were aspirated from the flasks, harvested by centrifugation, washed and resuspended in RPMI.

25   The human lung carcinoma cell line A549 (ATCC CLL 185) was cultured as described above but without 2-mercaptoethanol in the medium. The cells were detached by versene (0.2 g Sodium EDTA per liter PBS) for about 10 min at 37^0C. Detached cells were harvested by centrifugation at 320 x *g* for 10 min and
30   resuspended in RPMI.

Human renal tubular epithelial cells (HRTEC) were isolated from the kidney of a three year old boy whose kidney was removed due to hydronephrosis and reduced function. Renal
35   cotex was dissected from renal medulla, minced and collected by centrifugation at 250 x *g* for 10 min. The cortical

fragments were incubated overnight at 4^0C on a rotational
platform in phosphate buffered saline (PBS) 0.15M pH7.2
containing 0.1% collagenase type I (Sigma) and 0.04% DNAse
type IV (Sigma). Tissue was collected by centrifugation (250 x

5   g for 10 min) and diluted in an equal volume HBSS,
supplemented with 15% fetal calf serum. The tissue was
resuspended in eight volumes of HBSS with 15% FCS, applied to
the top of a two step Percoll gradient: 30 and 50% diluted in
HBSS, centrifuged at 1500 x g for 20 min at 4^0C and the

10   interface collected. This interface was diluted in four
volumes of HBSS with 15% FCS, centrifuged at 250 x g for 10
min and resuspended in Primaria flasks in Dulbecco's modified
Eagle's medium supplemented with 15% FCS, 2 mM L-glutamine, 20
units/ml heparin, 100 U/ml of penicillin and 100µg/ml

15   streptomycin. Cells were incubated at 37^0C in an atmosphere of
95% air and 5% C_{o2} and grown to confluence. After
trypsinization the cell suspension was filtered through a 35µm
nylon mesh, replated in Primaria flasks and grown to
confluence. The cell isolates were trypsinized, concentrated

20   in FCS containing 5% DMSO and stored in liquid nitrogen for
subsequent use. Cells used in experiments were passaged 3-4
times and cultured as above for A549 cells.

MAL was purified from frozen milk as described for example in

25   WO 96/04929. Briefly, human milk was thawed and centrifuged to
remove fat. The defatted milk was separated into casein and
whey by acid precipitation (O. Melander, 1947, Uppsala
Läkarfören, Förhandl. 3-4: 107-198). The casein precipitate
was harvested by centrifugation, washed by 3-5 cycles of

30   resuspension in distilled water and lyophilised. The casein
was fractionated using an ion-exchange column packed with
DEAE-Trisacryl M attached to an FPLC instrument (Pharmacia-
LKB, Uppsala, Sweden) with a NaCl gradient. The MAL complex
eluted with 1 M NaCl. The eluant was desalted by dialysis

35   (membrane cut off 3.5kD) against distilled water for at least
48h, lyophilised and resuspended to appropriate
concentrations.

Example 1

Susceptability of cells to MAL-induced apoptosis

L1210, A549 and HRTEC cells were resuspended in RPMI (2×10^6

5   cells/ml). The cell suspension (900 µl) was mixed with MAL
(100 µl) in a 24-well plate incubated for 6 h or 24 h
respectively, at 37^0C and harvested by aspiration. Cell
aliquots were tested for viability by trypan blue exclusion.
Remaining cells were analysed for DNA fragmentation.

10

DNA fragmentation was detected by agarose gel electrophoresis
(Håkansson et al. (1995)supra.). Briefly, cells (2×10^6) were
suspended in 250µl of TE-buffer (10 mM Tris, 1mM EDTA, pH 8.0)
and 250µ of ice-cold lysis buffer (0.5% Triton X-100, 5 mM

15   Tris, 20mM EDTA, pH 8.0), vortexed and allowed to lyse on ice
for 1 h. DNA fragments were separated from intact chromatin by
centrifugation at 13,000 x g for 15 min. The supernatant was
transferred to new tubes and DNA was precipitated at -20^0C
after addition of 1ml cold, absolute ethanol and 25µl of 5M

20   NaCl. Precipitated DNA was pelleted by centrifugation at
13,000 x g for 15 min and dried in a Speed-Vac Concentrator
(Savant Instruments Inc., Farmingdale, NY, USA) until ethanol
had vaporised. The pellet was resuspended in 30µl of TE-buffer
and incubated for 1h at 37^0C with 1mg/ml of RNAse A followed by

25   1h with 500µg/ml of Proteinase K. Samples were loaded on 1.8%
agarose gels, and run overnight applying a 40 V constant
voltage. DNA was visualised under ultraviolet light (305 nm)
after straining with ethidium bromide (6 µg/ml) and
photographed using Polaroid 55 positive-negative film. DNA

30   size was calibrated using 1 kD DNA ladder (Gibco BRL, Life
Technologies LTD., Paisley, UK), consisting of 1018 bp dsDNA
fragment repeats and vector DNA ranging from 75-1636 bp.

High molecular weight DNA fragments were detected by field-

35   inversion gel electrophoresis (FIGE). Briefly, cells (2×10^6)
were suspended in 180 µl of buffer (0.15 M NaClaniacal, 2 mM
KH_2PO_4/KOH, pH 6.8, 1 mM EGTA, 5mM $MgCl_2$) and 180 µl of 37^0C

molten 1% low melting point agarose gel (SeaKem, FMK
Bioproducts, Rockdale, USA) and pipetted into plugs at
precoled plates and left for 10 min at 4°C. The plugs were
incubated in 1ml/plug of incubation buffer (10 mM NaCl, 10 mM

5   Tris, pH 9.5, 25 mM EDTA, 1% N-lauroylsarcosine, supplemented
with proteinase K at a final concentration of 0.2 mg/ml) at
50°C for 24 h. The incubation was followed by rinsing in 3
changes of TE-buffer at 4°C for 2h. The plugs were stored in
50mM EDTA until run. Electrophoresis were run at 180V in 1%

10   agarose gels in 0.5 x TBE (45 mM Tris, 1.25mM EDTA, 45 mM
boric acid, pH 8.0), at 12°C, with the ramping rate changing
from 0.8s to 30s for 24h, using a forward to reverse ratio of
3:1. DNA size calibration was performed using two sets of
pulse markers: chromosomes from *Saccharomyces cerevisiae* (225-

15   2200 kbp) and a mixture of λDNA and λDNA concatemers (0.1-
200kbp) purchased from Sigma. Gel staining and photography
were performed as described above.

The L1210 cells died when exposed to 0.5 mg/ml of MAL, with

20   50% of the cells remaining viable after 6 h (Fig. 1A). The
A549 cells required a higher concentration (1.25 mg/ml of MAL)
and a longer incubation time (24 hours) in order for 50% of
the cells to loose their viability (Fig. 1A). The HRTEC cells
remained fully viable after 24 h incubation with up to 4 mg/ml

25   of MAL. Monomeric α-lactalbumin had no effect on cell
viability even at 10mg/ml.

The kinetics of DNA fragmentation are illustrated in Fig. 1B.
DNA fragmentation was highly time and concentration dependant.
HMW DNA fragments were observed in the L1210 cells after 30

30   min incubation with MAL (0.5 mg/ml) and oligonucleosome length
DNA fragments were detected after three hours. At lower MAL
concentrations (0.3mg/ml) fragmentation of DNA was first seen
after 6 h and at higher concentrations of MAL (0.75mg/ml)
fragmentation was seen already at 2 h. At later times no

35   fragmentation was seen due to secondary lysis of cells.

In the A549 cells HMW fragmentation was first detected after 6 h incubation with 1.0mg/ml and was maximal at 1.5 mg/ml (Fig. 1B, panel 1). Further breakdown of DNA was observed with higher concentrations of MAL until finally no chromosomal DNA

5   was seen (2.5 mg/ml). No oligonculeosomal fragmentation was detected (Fig. 1B, panel II).

The HRTEC cells did not undergo HMW DNA fragmentation after exposure to 4 mg/ml of MAL for 24 h (Fig. 1B).

These results demonstrated that differential sensitivity to

10 MAL-induced apoptosis among the cell types studied. The L1210 cell line was highly sensitive, the A549 cells were intermediately sensitive and the non-transferred cultures were resistant to the effects of the protein complex within the tested concentration range. The monomeric form of the protein

15 was inactive.

Example 2

Cell surface binding of MAL complexes

20 MAL, human α-lactalbumin (HLA) and immunoglobulin G were biotinylated according to the manufacturer's instructions or labelled with ^{125}I with the lactoperoxidase method. Proteins were dissolved in PBSA-T buffer (30 mM Na_2HPO_4, 120mM NaCl, pH 7.4, with 0.1% NaAzid, 0.05% Tween-20) and 25 μl of protein

25 (25 μg) was incubated with 2μl of ^{125} (0.2Ci), 2 μl of lactoperoxidase (2.5mg/ml) and 2 μl of H_2O_2 (diluted 1:2000 in PBS) for 2 min at room temperature. The reaction was stopped by the addition of 500 μl of PBSA-T. The labelled protein was purified on a PD-10 column. 500 μl fractions in PBSA-T were

30 eluted and fractions containing radioactivity were stored at - 20°C. The labelled protein eluted in 1 ml of buffer and had an activity of approximately 2 x 10^8 cpm.

L1210, A549 and HRTEC cells (3 x 10^6 cells/ml, 50µl) were
incubated in suspension with 50µl of biotinylated MAL, ALA or
BSA for various times at 37^{0}C. The cells were washed with PBS
by centrifugation at 320 x g for 10 min and the supernatant

5   was discarded. FITC-conjugated streptavidin (diluted 1:50 in
PBS) was added and the cells were incubated for 30 min at room
temperature. The cells were washed by centrifugation as above,
suspended in 300 µl PBS and the surface fluorescence was
analysed by flow cytometry on a Coulter Epics Profile II flow

10   cytometer (Coulter Inc.), equipped with a 488 nm argon laser.
Green fluorescence was detected with a 525nm band pass filter.
The PMT voltage was initially set to1250 V and adjusted for
day to day variation using calibration with Immunobeads
(Coulter).

15   Cell surface bound material was examined by confocal
microscopy, and quantitated by flow cytometry. Binding to the
three cell types was detected after 10 min and reached a
maximum after 30 min incubation, with a fluorescence intensity
measured by flow cytometry that was 12.1, 13.4 and 8.5 times

20   that of the streptavidin control. MAL was distributed in
patches separated by unstained areas (Fig. 2A) seen on
confocal microscopy.

Cell surface binding of MAL was also quantitated as the cell
associated radioactivity during the first 30 min after

25   addition of ^{125}I-labelled MAL to the cells (Fig. 2B).   Surface
binding of radiolabelled protein to L1210, A549 or HRTEC cells
in suspension (3 x 10^6 cells/ml, 100 µl) was quantitated in an
Epics γ-counter (Coulter Inc.) after incubation with 1 x 10^6
cpm of ^{125}I-labelled MAL, ALA or IgG for 30 min at 37^{0}C and the

30   cells were washed three times by centrifugation at 320 x g for
10 min with PBS.

Binding increased with the concentration of MAL, reaching
saturation at 23 000, 20 000 and 18 000 cpm for L1210, A549
and HRTEC cells, respectively, after 30 min of exposure to 2 x

10^6 cpm compared to 1500 and 1300cpm for L1210, and A549 cells
of IgG. There was no difference in cell surface binding of
MAL between the three cell types (Fig. 2B). Employing this
method the binding of -125^I labelled ALA was lower than that of

5   MAL. After 30 minutes of exposure to 2 x 10^6cpm of ALA binding
was 5 000, 7 000 and 7 500 cpm for the L1210, A549 and HRTEC
cells, respectively.

Example 3

Nuclear uptake of MAL

10   To detect intracellular protein, the cells were fixed at
various times after addition of 0.3 mg/ml of biotinylated MAL
for 5 min in phosphate-buffered paraformaldehyde (4%) (B.
Sander et al., Immunol. Rev. (1991) 119: 65-92) at room
temperature, washed in PBS, and permeabilized with 0.1%

15   saponin in PBS. FITC conjugated streptavidin (diluted 1:100 in
0.1% saponin) was added and the cells were incubated for 30
min at room temperature. The cells were washed twice in PBS-
saponin and once in PBS, mounted on a glass slide and analysed
in a Bio-Rad 1024 laser scanning confocal equipment (Bio Rad

20   Laboratories, Hemel-Hempstead, UK) attached to a Nikon Diaphot
inverted microscope.

Permeabilization with the saponin allowed entry of
streptavidin. Cells treated with medium, biotinylated BSA or
α-lactalbumin served as controls (Fig.3). Nuclear uptake of

25   MAL was shown to occur rapidly in cells that were sensitive to
its apoptosis-inducing effects. Nuclear staining of L1210
cells was first detected after about 2 hours in about 10% of
the cells, and after 6 hours more than 70% of L1210 cell
nuclei stained brightly. Cytoplasmic staining was not observed

30   in those cells. Nuclear localisation of MAL in the A549 cells
required longer incubation times (Fig. 3). About 15% of A549
cell nuclei stained brightly. In the meantime, MAL was
observed in the cytoplasm of A549 cells as granular
fluorescence evenly distributed throughout the cell. Nuclear

uptake was not observed in the HRTEC cells exposed to the
biotinylated MAL (1mg/ml). There was a marked difference in
the nuclear uptake of ALA compared to MAL. Nuclear staining
of ALA was only detected in circa. 30% of L1210 cells after 6
5   hours and in about 15% OF A549 cells after 24 hours. No
staining of ALA was detected in the HRTEC cells.

Example 4

Radiolabelled Studies of Intracellular distribution.

The intracellular distribution of MAL was further analysed in
10   cells exposed to ^{125}I-labelled MAL with ^{125}I-labelled α-
lactalbumin and IgG as controls (Fig. 4). Subcellular
fractions were prepared after mechanic disruption of the cells
and the amount of radiolabelled MAL in each fraction was
determined in relation to the total cell-associated
15   radioactivity measured prior to disruption of the cells.
Fraction P1 contained mostly cell nuclei, P2 contained plasma-
, Golgi-, ER-membranes and mitochondria, P3 contained small
vesicles and the supernatant. Fraction S contained the
cytosolic proteins. The purity of the fractions was determined
20   by quantitation of specific markers (DNA, alkaline
phosphatase, RNA and catalase).

Specifically, cellular subfractionation was performed as
described (J. Graham., Isolation of subcellular organelles and
membranes., p161-1019. in D. Rickwood ed., Centrifugation, a
25   practical approach, 2nd ed. IRL Press, Washington DC). L1210,
A549 or HRTEC cells in suspension (3 x 10^6 cells/ml, 100 μla
were incubated with 1 x 10^6 cpm of ^{125}I-labelled MAL, ALA or IgG
for various times at 37^{0}C. The cells were washed three times
with ice-cold PBS and the supernatants were discarded. The
30   cells were suspended in 500 μl of homogenisation buffer (10 mM
Tris-HCl, pH 7.8, 5 mM MgCl$_2$ and 2 mM CaCl$_2$ for L1210 cells and
0.15M NaCl, 2 mM EDTA, pH 7.5 for A549 cells), and homogenised
by 50 strokes in a Dounce homogenizer (Thomas, Philadelphia,
USA) with pestle size 415. Sucrose was added to a final

concentration of 250 mm and the homogenate was centrifuged at 100 x g for 25 min at RT. The first pellet contained nuclei, large mitochondria and large sheets of plasma membrane. The remaining supernatant was further centrifuged at 12 000 x g

5 for 30 min at 4^0C resulting in a second pellet containing mitochondria endoplasmic reticulum, plasma membrane and cytoplasmic organelles. The supernatant was finally centrifuged at 150 000 x g for 2 h at 4^0C resulting in a pellet containing small vesicles, endoplasmic reticulum and a

10 supernatant containing cytosolic proteins.

Specific cellular compartments were detected using enzymatic or chemical assays as described (Graham. supra. P.309-333).

DNA and RNA were detected in the fractions by the binding of ethidium bromide. Sample (1 vol) was mixed with 1 vol of

15 heparin solution (25 μg/ml) and 1 ml of PBS or with 1 vol of heparin, 1 vol of RNAse A (50 μg/ml) and 1 vol of PBS. The samples were incubated at 37^0C for 20 min and 1 vol of ethidium bromide was added (25 μg/ml). Fluorescence was measured after 60 s incubation using an excitation wavelength of 360 nm and

20 an emission wavelength of 580 nm. PBS served as blank, 1 vol of homogenate in 4 vol of PBS served as background correction factor and the fluorescence was compared to a DNA standard (25 μg/nl of λDNA).

Catalase activity was measured by mixing sample (0.5 ml) with

25 H_2O_2 (0.5 ml), for 3 min at 4^0C. H_2SO_4 (0.1 ml) was added to stop the reaction, $KMnO_4$ (0.7 ml) was added and the optical density of the sample was measured at 480nm within 1 min.

Alkaline phophatase activity was detected by mixing 50 μl of sample with 200 μl of assay mixture (5 ml of 16mM p-

30 nitrophenylphosphate solution, 5 ml of 50 mM sodium borate buffer (pH 9.5) and 20 μl of 1 M $MgCl_2$) and incubated at 37^0C for 60 min. The absorbance was measured at 410nm.

The distribution of ^{125}I-labelled MAL and kinetics of uptake in the different cellular compartments, are shown in Fig. 4. As with biotinylated MAL there were differences in nuclear localisation of ^{125}I-labelled MAL between the cell types. MAL

5 accumulated in nuclei of L1210 cells with about 78% of the total radioactivity (34200/44000) recovered from the nuclear fraction (P1) after 6 h. MAL uptake into the nuclei of HRTEC cells was slow was slow with only 16% (2200/14000) of the total cell associated radioactivity in the nuclear fraction

10 after 24 h of incubation. The A549 cells formed an intermediary group with about 52% of ^{125}I-labelled MAL in the nuclear fraction (13700/27000) after 24 h. The total amount of cell-associated MAL in the other subcellular fractions did not differ to the same degree between the cell types. At the

15 final time-point of measurement 4500cpm (10%), 5100 cpm (195) and 2100 cpm (15%) were found in the pellet 2 from the L1210, A549 and HRTEC cells , respectively, and 800 cpm (2%), 1400 cpm (5%) and 1100 cpm (8%) were found in pellet 3 and 4500 cpm (10%), 6800 cpm (25%) and 8600 cpm (61%0 were found in the

20 cytosolic fractions.

These results with biotinylated ALA were confirmed using ^{125}I-labelled ALA. The monomeric protein entered the cells with lower efficiency than MAL, and was mainly recovered from the cytosol and not from the nuclei (Fig. 5). The nuclear uptake

25 of ^{125}I-labelled ALA in L1210, A549 and HRTEC cells was 23%, 27% and 37% of that observed for ^{125}I-labelled MAL in the respective cell types. The cytoplasmic localisation of radiolabeled ALA was 80%, 75% and 60% of the amount measured for radiolabeled MAL.

30 The cellular localisation studies with biotinylated and ^{125}I-labelled MAL suggested that MAL was transported into the nuclei and that the nuclear uptake of MAL into different cells was proportional to their sensitivity to MAL-induced apoptosis.

Example 5

Effects of MAL complexes on Isolated Nuclei

Nuclei were purified from L1210, A549 and HRTEC cells and

5   incubated with low concentrations of MAL (0.2 and 0.4 mg/ml).
The formation of HMW and oligonucleosome length DNA fragments
was examined.

A549, L1210 and HRTEC nuclei were isolated from homogenised
cells. Pellet 1 from the homogenisation was washed twice in

10   nuclei buffer for 20 min at 100 x g and suspended in nuclei
buffer for experiments. Rat liver nuclei was isolated.

A549, L1210 or HRTEC nuclei in suspension were placed in
individual wells in a 24-well plate (900 µl), mixed with MAL,
α-lactalbumin, lactoferrin or BSA (100 µl in nucleus buffer),

15   incubated at 37°C for 1 hour (L1210,) or 2 hours (A549 and
HRTEC), harvested by aspiration, analysed for DNA
fragmentation as described above. Inhibition of DNA
fragmentation was studied by preincubating the nuclei for 10
min at RT with 0.5mM EDTA, 10 µM BAPTA/ AM, 10µM verapamil, 1µM

20   VAD, 0.25 µM BOC, 0.5µg/ml calpeptin, 0.5 µM DCI.

Active nuclear uptake was performed according to Adams et al.
((1990) supra.), with some modifications.

Briefly, 1 x 10⁶ cells were incubated in 100 µl of nuclear
transport buffer (NTB), with the addition of 1 µg/ml each of

25   leupeptin, aprotinin, antipain, and 40 µg/ml of digitonin for
5 min at room temperature and washed by centrifugation at 320
x g for 10 min in NTB. Biotinylated protein (5 µl, 5mg/ml) was
added to the cells in a total volume of 100 µl NTB
supplemented with phosphcreatin, creatine phosphokinase and

30   ATP, incubated for various time at RT and washed twice in NTB

by centrifugation at 320 x g for 10 min. The cells were treated with 0.2% Triton-X100 in NTB for 6 min and washed finally 1:100 dilution of fluorescein-conjugated strepatvidin was added for 30 min at RT and washed. The cells were then
5   inspected by fluorescence microscopy in a Nikon Microphot (Japan) microscope or by laser scanning confocal microscopy in a BioRad MRC-1024 instrument.

A low degree of spontaneous DNA fragmentation occurred in unstimulated nuclei from the three cell types but MAL enhanced
10   the formation of HMW DNA fragments after one hour and oligonucleosome length fragments after 2 hours (Fig. 6).

Digitonin permeabilizes the plasma membrane, but leaves the nuclear membrane intact. L1210, A549 and HRTEC cells were permeabilized with digitonin in nuclear transport buffer,
15   washed and exposed to biotinylated MAL in buffer supplemented with phosphocreatin, creatin phosphokinase and ATP. Human IgG and monomeric α-lactalbumin were used as controls. MAL was taken directly into the nuclei of digitonin treated cells with maximum levels reached after 20 min (Fig. 7e).

20   When adding 0.4 mg/ml of MAL to digitonin-permeabilized cells, HMW DNA fragments were formed after 1 hour and oligonucleosomal fragments after 2 hours. ALA entered nuclei of digitonin-permabilzed cells as predicted by its molecular mass (14kDa) and produced bright staining of the nuclei (Fig.
25   7c). IgG was not detected in isolated nuclei or in nuclei of digitonin-permabilized cells (Fig. 7a).

These experiments demonstrated that both ALA and MAL was transported into the nuclei, but that only MAL could induce DNA fragmentation in isolated nuclei, apparently in the
30   absence of activated cytoplasm. There was however, no difference in sensitivity to MAL-induced DNA fragmentation between nuclei from the three cell types. This suggested that the differential sensitivity to MAL was determined by the

nuclear targeting process rather than by the effect on the nuclei *per se.*

Example 6

5   Role of the nuclear pore complex for the nuclear uptake of MAL.

The role of active transport over the nuclear pore was examined in digitonin-treated cells, using wheat-germ agglutinin (WGA) which binds to the nucleoporins and inhibits

10   the transport of importin-protein complex through the nuclear pore. The digitonin-permeabilized L1210 cells were preincubated with 50µg/ml of WGA for 20 minutes, washed and exposed to biotinylated MAL. IgG and α-lactalbumin were used as controls (Fig. 7).

15   Specifically, before adding biotinylated protein, cells were preincubated with 50µg/ml of wheat-germ agglutinin (WGA), 0.5mM EDTA, 0.5 mM BAPTA/AM or 10µM verapamil for 20 min at RT. The cells pretreated with WGA were then washed by centrifugation in NTB at 320 x *g* for 10 min before addition of

20   protein.

The integrity of the nuclear membrane was tested by adding sera containing anti-nuclear antibodies to digitonin- and Triton-X100 permeabilized cells followed by incubation with anti-human IgG antibodies (1:100) for 30 min at RT, washing by

25   centrifugation at 320 x *g* for 10 min and visualisation as described above. Permeabilization with Triton-X 100 resulted in bright nuclear staining whereas no detectable staining was observed in the digitonin-permeabilized cells at a concentration of 40 µg/ml of digitonin. (The antibodies were

30   kindly provided by the Clinical Immunology Laboratory, Lund).

WGA completely blocked the nuclear uptake of MAL, suggesting that transport was via the nuclear pore complex (Fig. 7f). Human IgG was not taken up in the presence or absence of WGA (Fig. 7a and 7b). Monomeric α-lactalbumin is a 14kDa protein

5 that diffuses freely over the nuclear membrane. WGA had no effect on the uptake of α-lactalbumin into the nuclei of digitonin-treated cells (Fig. 7d). Wheat germ agglutin was also used to inhibti DNA fragmentaton in isolated nuclei and digitonin-permeabilized cells. Preincubation with 50µg/ml of

10 WGA partially blocked the DNA fragmentation from exposure to 0.4 mg/ml of MAL (Fig. 6)

Example 7

Role of Ca^{2+} for nuclear uptake of MAL and for the induction of DNA fragmentation.

15 The MAL induced apoptosis was previously shown to require extracellular Ca^{2+}. This suggested that Ca^{2+} might influence the nuclear uptake mechanism and or the induction of DNA fragmentation once MAL reaches the cell nuclei. L1210, A549 and HRTEC cells were pretreated with inhibitors of Ca^{2+} uptake

20 (verapamil and nefidipine), with extracellular Ca^{2+} - chelators (EDTA and EGTA) and with an intracellular Ca^{2+} chelator (BAPTA/AM). ^{125}I-labelled MAL was added to the cells, and the nuclear uptake was examined after 6 hours in L1210 cells and after 24 hours in A549 and HRTEC cells. The Ca^{2+} uptake

25 inhibitors and chelators had no effect on the nuclear uptake of MAL (Fig. 8). The MAL induced DNA fragmentation was subsequently examined in control nuclei and nuclei incubated with Ca^{2+} inhibitors. Verapamil, EDTA and BAPTA/AM completely blocked the DNA fragmentation in L1210 and A549 nuclei. These

30 results demonstrated that DNA fragmentation by MAL required Ca^{2+}, but that the nuclear uptake of MAL was Ca^{2+} ^{I} independent.